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(54) **SOUND TO HAPTIC EFFECT CONVERSION SYSTEM USING AMPLITUDE VALUE**

(75) Inventors: **Juan Manuel Cruz-Hernandez**, Montreal (CA); **Herve Thu Timone**, Montreal (CA); **Jason Hoi Fun Lau**, Foster City, CA (US)

(73) Assignee: **IMMERSION CORPORATION**, San Jose, CA (US)

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(52) **U.S. Cl.**
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USPC 340/407.1, 407.2; 704/224, 225, 704/E19.012, 200; 345/156, 161; 463/36, 463/30, 42; 369/2, 4, 5, 47.2, 275.3; 381/63, 119, 102, 104–107, 56
See application file for complete search history.

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*Primary Examiner* — Steven Lim
Assistant Examiner — Mancil Littlejohn, Jr.
(74) *Attorney, Agent, or Firm* — Miles & Stockbridge P.C.

(57) **ABSTRACT**

A haptic conversion system is provided that intercepts frames of audio data, such as a digital audio signal, converts the frames into a haptic signal, and plays the created haptic signal through an actuator to produce haptic effects. The haptic signal is based on a maximum value of each audio data frame, which defines a magnitude of the haptic signal. The haptic signal is applied to the actuator configured to receive the haptic signal, where the actuator utilizes the haptic signal to generate the one or more haptic effects.

26 Claims, 8 Drawing Sheets
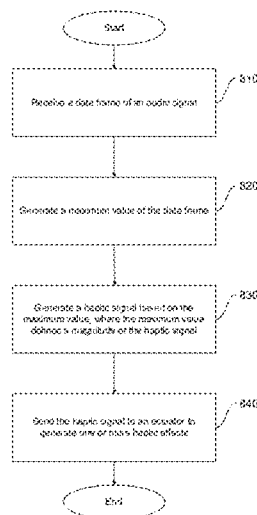
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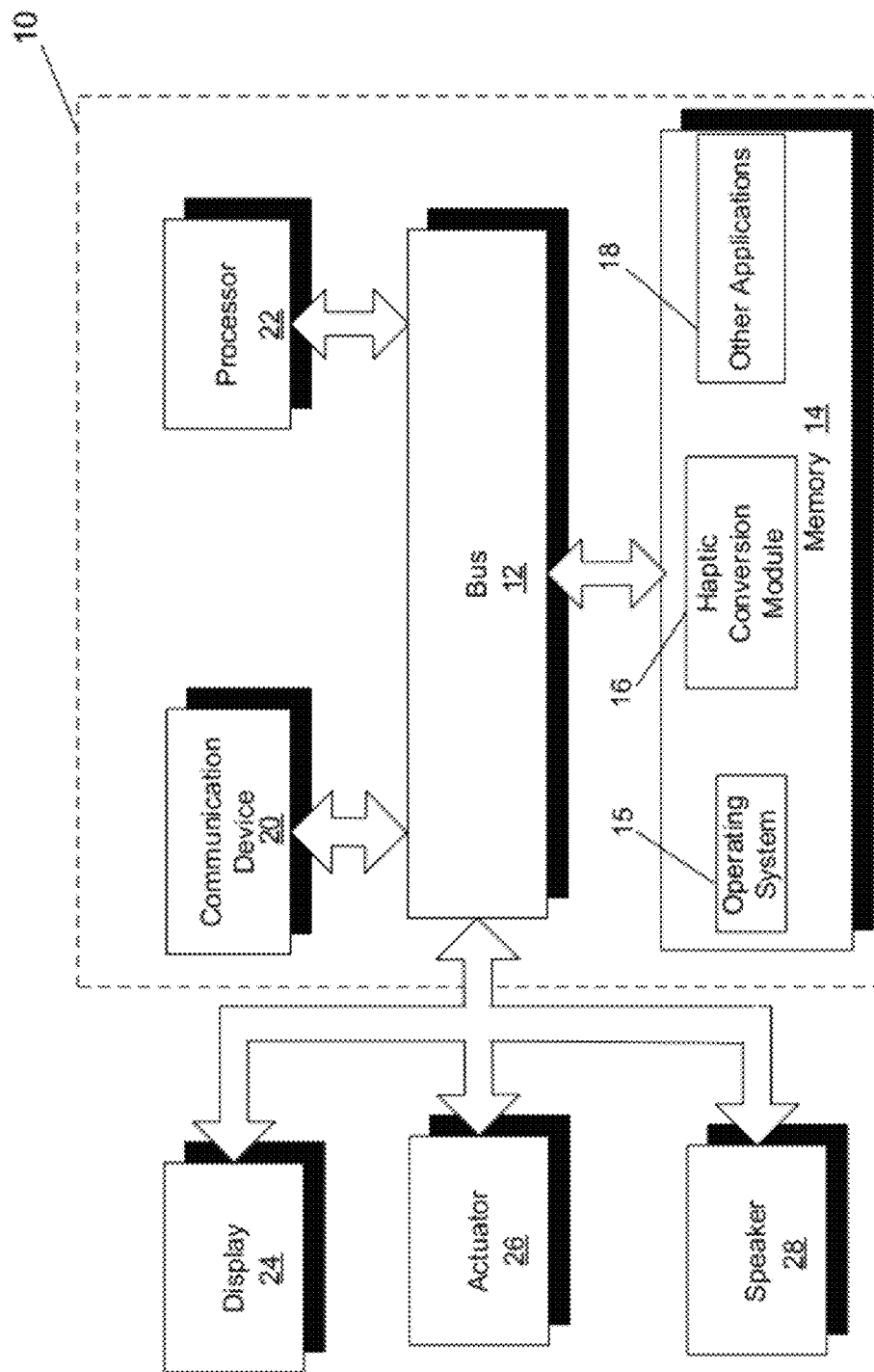Ricky Bhatia et al., U.S. Appl. No. 13/366,010, filed Feb. 3, 2012.
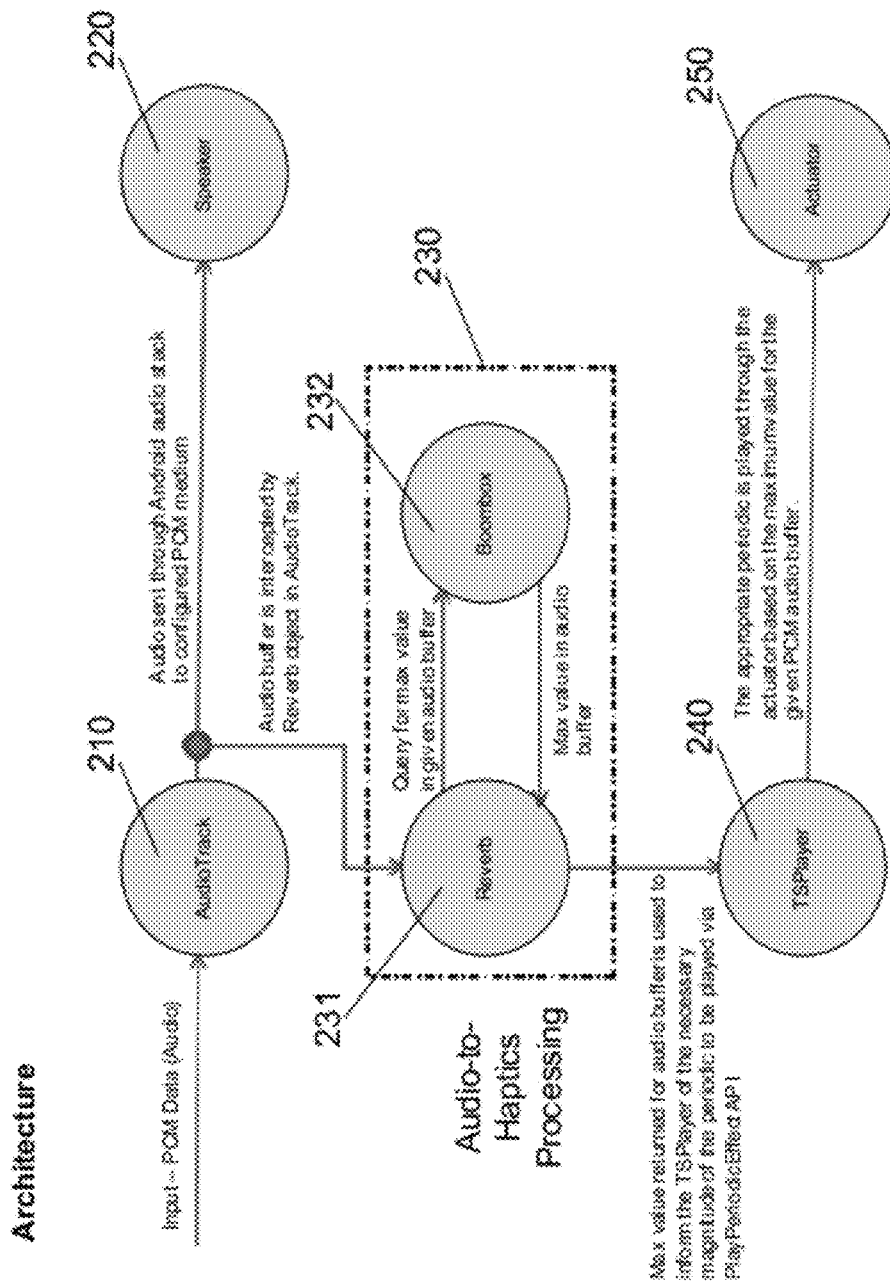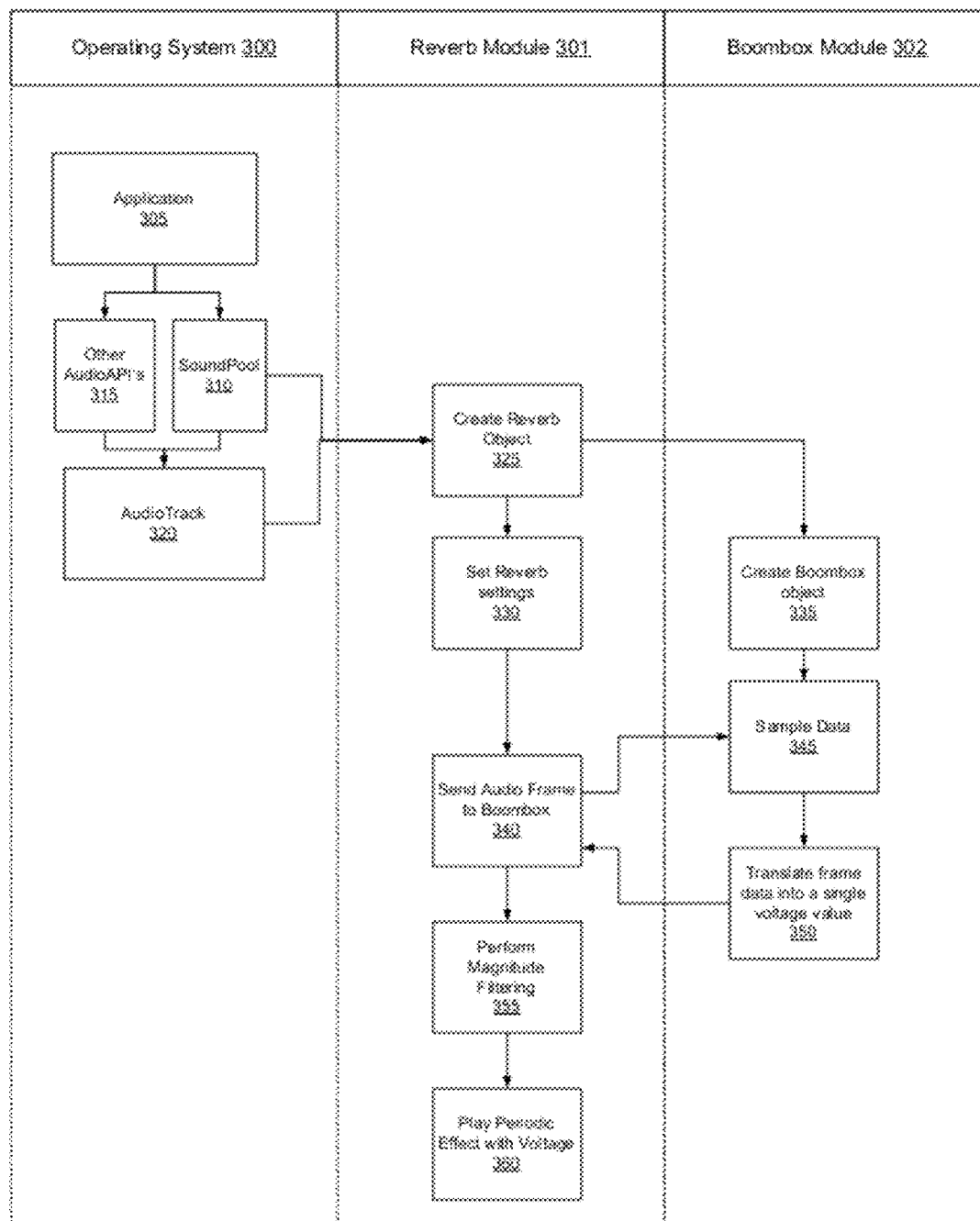
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Fig. 1

Architecture

Input – PCM Data (Audio)

210

220

Audio sent through Android audio stack
to configured PCM medium

Audio buffer is intercepted by
Reverb object in AudioTrack.

232

230

Query for max value
in given audio buffer

Max value in audio
buffer

231

Audio-to-
Haptics
Processing

Max value returned for audio buffer is used to
inform the TS Player of the necessary
magnitude of the periodic to be played via
PlayPeriodicEffect API.

240

250

The appropriate periodic is played through the
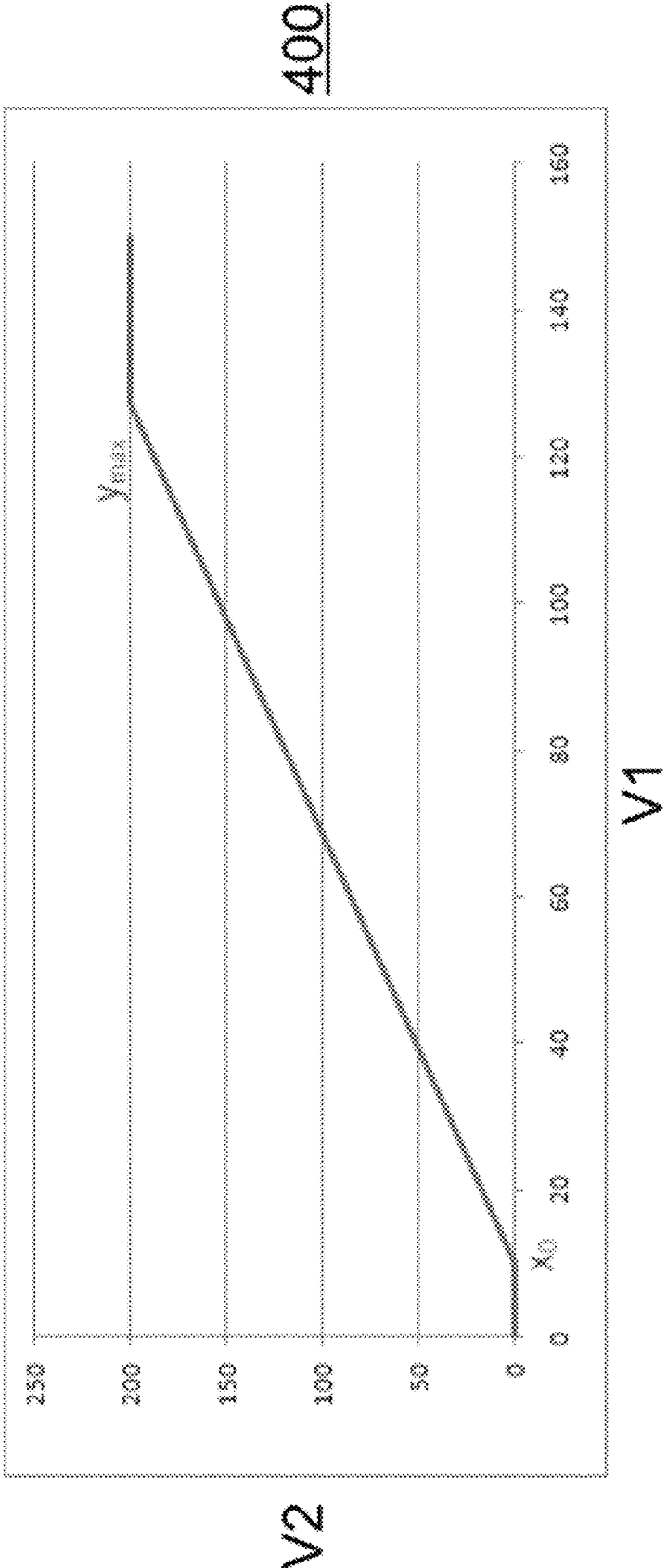actuator based on the maximum value for the
given PCM audio buffer.

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Start

Receive a data frame of an audio signal — 810

Generate a maximum value of the data frame — 820

Generate a haptic signal based on the maximum value, where the maximum value defines a magnitude of the haptic signal — 830

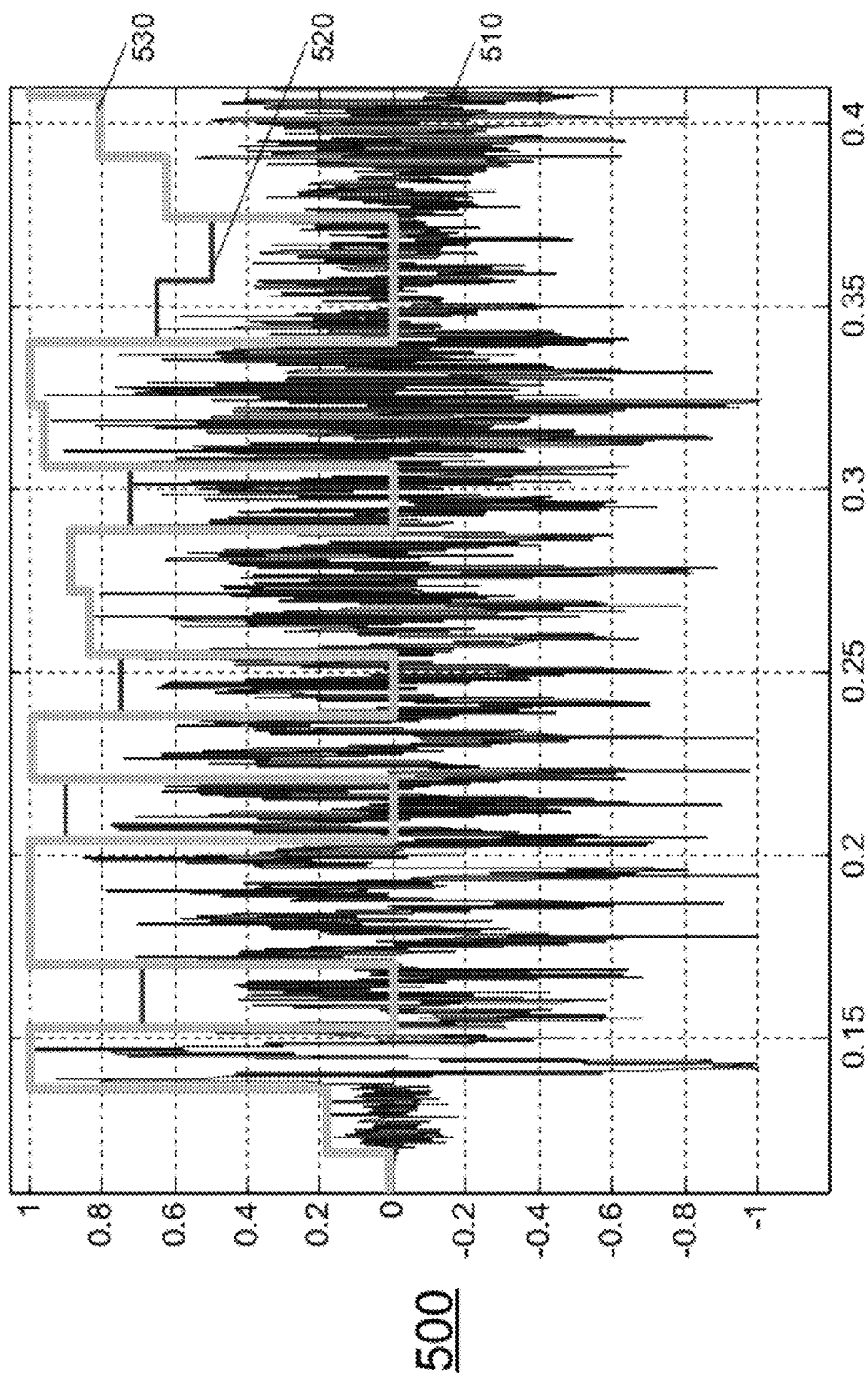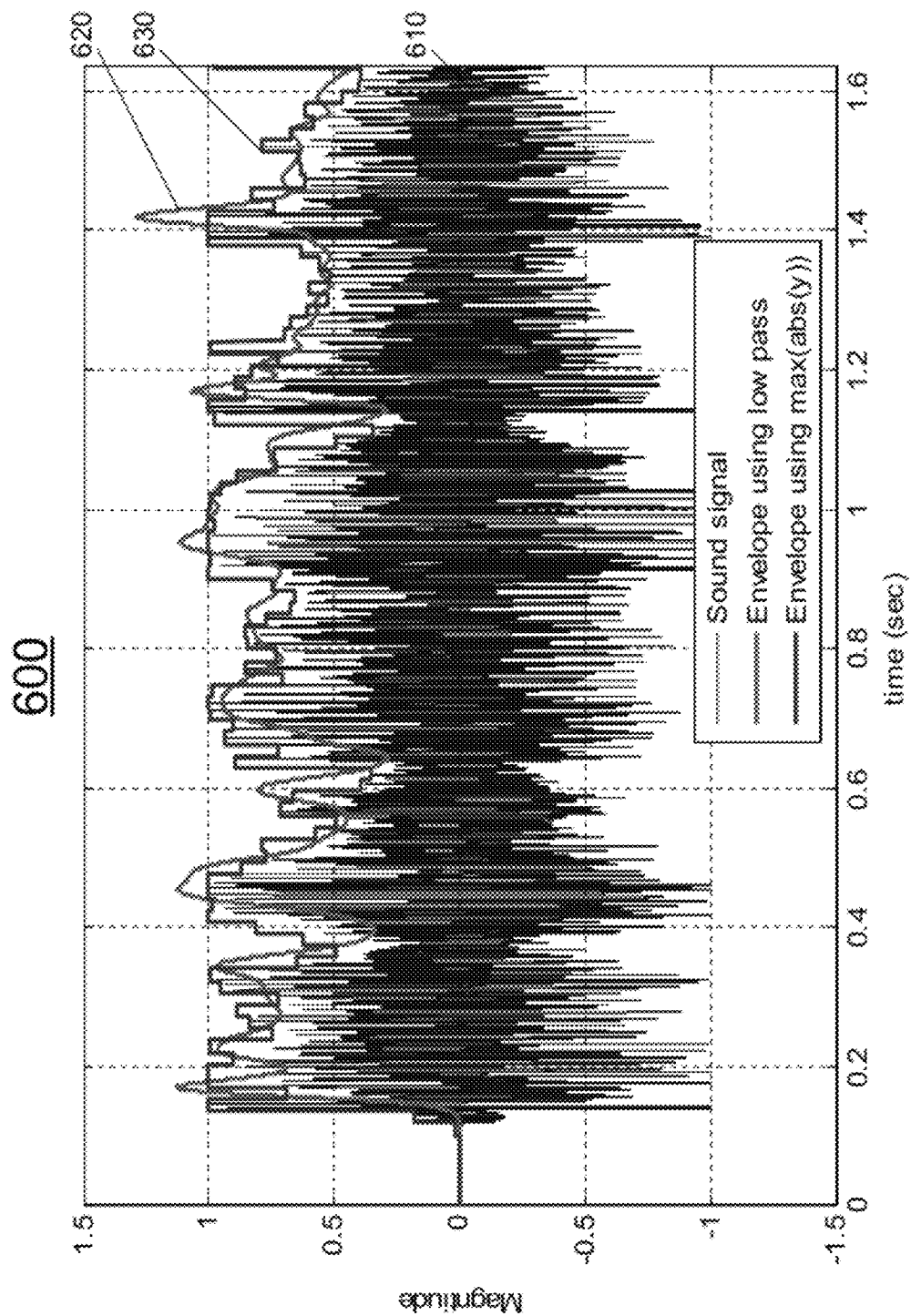Send the haptic signal to an actuator to generate one or more haptic effects — 840

End
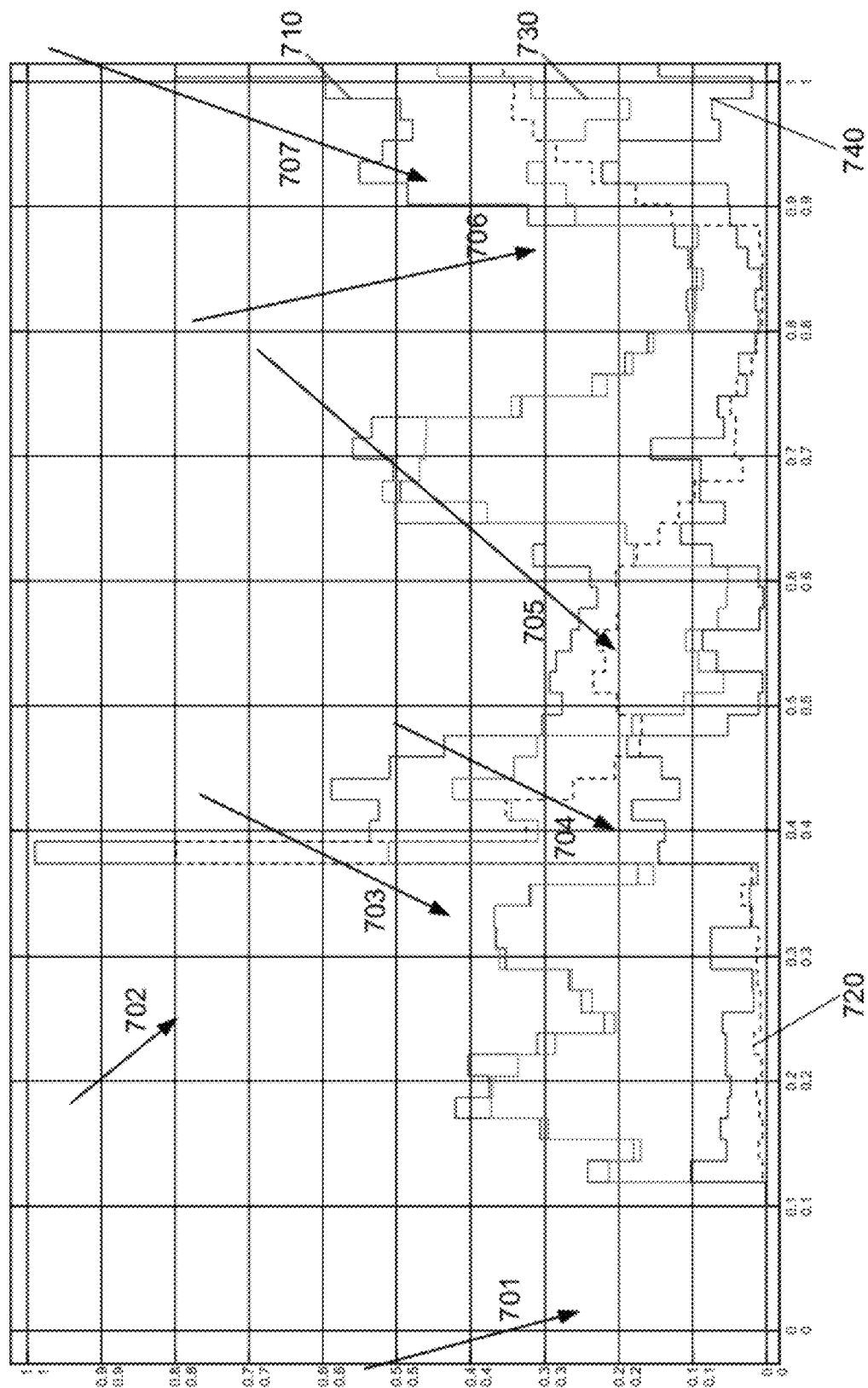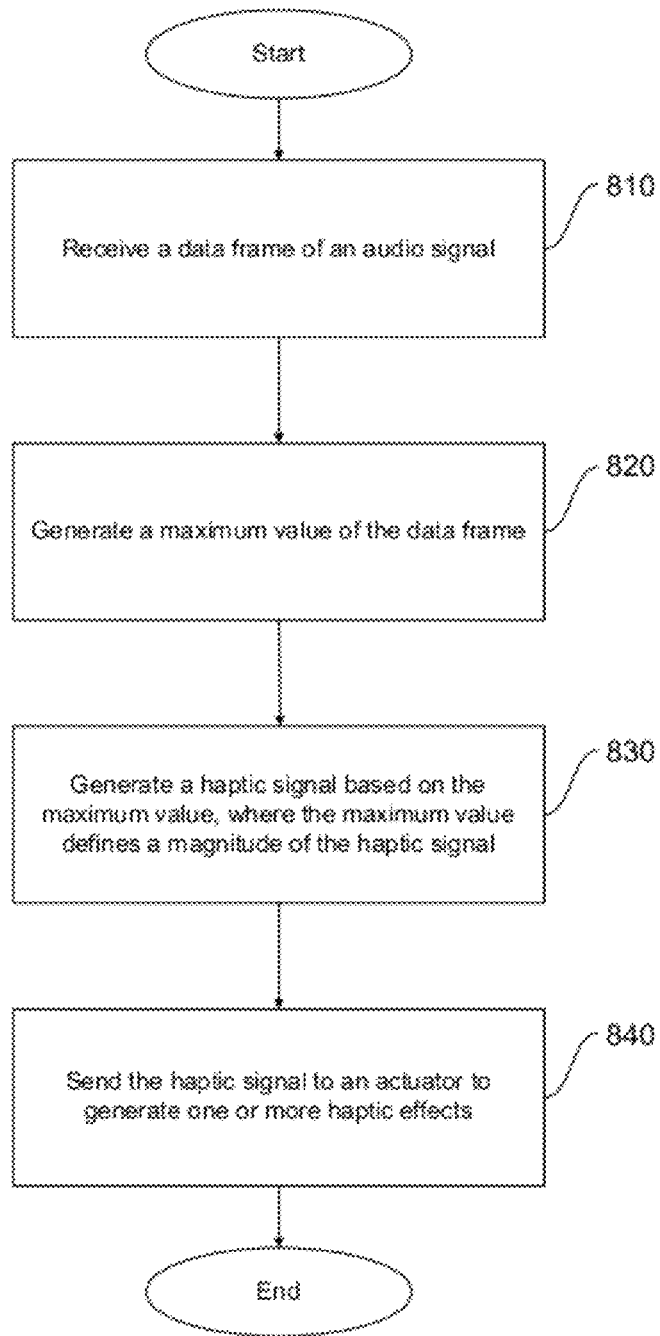
Fig. 8

SOUND TO HAPTIC EFFECT CONVERSION SYSTEM USING AMPLITUDE VALUE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority of U.S. Provisional Patent Application Ser. No. 61/441,792, filed on Feb. 11, 2011, the disclosure of which is hereby incorporated by reference.

FIELD

One embodiment is directed generally to a device, and more particularly, to a device that produces haptic effects.

BACKGROUND

Haptics is a tactile and force feedback technology that takes advantage of a user's sense of touch by applying haptic feedback effects (i.e., "haptic effects"), such as forces, vibrations, and motions, to the user. Devices, such as mobile devices, touchscreen devices, and personal computers, can be configured to generate haptic effects. In general, calls to embedded hardware capable of generating haptic effects (such as actuators) can be programmed within an operating system ("OS") of the device. These calls specify which haptic effect to play. For example, when a user interacts with the device using, for example, a button, touchscreen, lever, joystick, wheel, or some other control, the OS of the device can send a play command through control circuitry to the embedded hardware. The embedded hardware then produces the appropriate haptic effect.

Such devices can also be configured to play audio data, such as a digital audio signal. For example, such devices can include applications configured to play video data, such as a movie or video game, that contains an audio portion, or audio data, such as a song. Similar to haptics, calls to additional embedded hardware capable of generating audio effects (such as speakers) can be programmed within the OS of the device. Thus, the OS of the device can send a play command through control circuitry to the additional embedded hardware, where the additional embedded hardware then produces the appropriate audio effect.

SUMMARY

One embodiment is directed to a system that converts an audio signal into one or more haptic effects. The system receives a data frame of the audio signal. The system further generates a maximum value of the data frame. The system further generates a haptic signal based on the maximum value, where the maximum value defines a magnitude of the haptic signal. The system further sends the haptic signal to an actuator to generate the one or more haptic effects.

BRIEF DESCRIPTION OF THE DRAWINGS

Further embodiments, details, advantages, and modifications will become apparent from the following detailed description of the preferred embodiments, which is to be taken in conjunction with the accompanying drawings.

FIG. 1 illustrates a block diagram of a haptic conversion system in accordance with one embodiment of the invention.

FIG. 2 illustrates an architecture diagram of a haptic conversion system, according to one embodiment of the invention.

FIG. 3 illustrates a flow diagram of functionality performed by a haptic conversion system, according to one embodiment of the invention.

FIG. 4 illustrates a linear conversion function that is applied to control a range of an output value, according to one embodiment of the invention.

FIG. 5 illustrates an example computation of a magnitude of a haptic effect that is created based on a digital audio signal, according to one embodiment of the invention.

FIG. 6 illustrates an example calculation of an envelope of a digital audio signal, according to one embodiment of the invention.

FIG. 7 illustrates an example calculation of an envelope of a digital audio signal based on frequency content, according to one embodiment of the invention.

FIG. 8 illustrates a flow diagram of the functionality of a haptic conversion module, according to one embodiment of the invention.

DETAILED DESCRIPTION

One embodiment is a haptic conversion system that can intercept one or more frames of audio data, such as a digital audio signal, convert the one or more frames into a haptic signal, and play the created haptic signal through an actuator to produce one or more haptic effects. The haptic signal can include a single control parameter. The haptic signal can be applied to a type of actuator configured to receive a single control parameter, where the actuator can utilize the single control parameter to generate the one or more haptic effects.

FIG. 1 illustrates a block diagram of a haptic conversion system 10 in accordance with one embodiment of the invention. In one embodiment, system 10 is part of a mobile device, and system 10 provides a haptic conversion functionality for the mobile device. Although shown as a single system, the functionality of system 10 can be implemented as a distributed system. System 10 includes a bus 12 or other communication mechanism for communicating information, and a processor 22 coupled to bus 12 for processing information. Processor 22 may be any type of general or specific purpose processor. System 10 further includes a memory 14 for storing information and instructions to be executed by processor 22. Memory 14 can be comprised of any combination of random access memory ("RAM"), read only memory ("ROM"), static storage such as a magnetic or optical disk, or any other type of computer-readable medium.

A computer-readable medium may be any available medium that can be accessed by processor 22 and may include both a volatile and nonvolatile medium, a removable and non-removable medium, a communication medium, and a storage medium. A communication medium may include computer readable instructions, data structures, program modules or other data in a modulated data signal such as a carrier wave or other transport mechanism, and may include any other form of an information delivery medium known in the art. A storage medium may include RAM, flash memory, ROM, erasable programmable read-only memory ("EPROM"), electrically erasable programmable read-only memory ("EEPROM"), registers, hard disk, a removable disk, a compact disk read-only memory ("CD-ROM"), or any other form of a storage medium known in the art.

In one embodiment, memory 14 stores software modules that provide functionality when executed by processor 22. The modules include an operating system 15 that provides operating system functionality for system 10, as well as the rest of a mobile device in one embodiment. The modules

further include a haptic conversion module **16** that converts an audio signal into a haptic signal that is used to produce one or more haptic effects, as disclosed in more detail below. In certain embodiments, haptic conversion module **16** can comprise a plurality of modules that each provide specific individual functionality for converting an audio signal into a haptic signal that is used to produce one or more haptic effects. System **10** will typically include one or more additional application modules **18** to include additional functionality, such as MOTIV® Haptic Development Platform by Immersion Corporation.

System **10**, in embodiments that transmit and/or receive data from remote sources, further includes a communication device **20**, such as a network interface card, to provide mobile wireless network communication, such as infrared, radio, Wi-Fi, cellular network, or other next-generation wireless-data network communication. In other embodiments, communication device **20** provides a wired network connection, such as an Ethernet connection or a modem.

Processor **22** is further coupled via bus **12** to a display **24**, such as a Liquid Crystal Display ("LCD"), for displaying a graphical representation or user interface to a user. The display **24** may be a touch-sensitive input device, such as a touch screen, configured to send and receive signals from processor **22**, and may be a multi-touch touch screen.

System **10** further includes one or more actuators **26**. Processor **22** may transmit a haptic signal associated with a haptic effect to actuator **26**, which in turn outputs haptic effects. Actuator **26** may be, for example, an electric motor, an electro-magnetic actuator, a voice coil, a shape memory alloy, an electro-active polymer, a solenoid, an eccentric rotating mass motor ("ERM"), a linear resonant actuator ("LRA"), a piezoelectric actuator, a high bandwidth actuator, an electroactive polymer ("EAP") actuator, an electrostatic friction display, or an ultrasonic vibration generator.

In some embodiments, system **10** further includes one or more speakers **28**. Processor **22** may transmit an audio signal to speaker **28**, which in turn outputs audio effects. Speaker **28** may be, for example, a dynamic loudspeaker, an electrodynamic loudspeaker, a piezoelectric loudspeaker, a magnetostrictive loudspeaker, an electrostatic loudspeaker, a ribbon and planar magnetic loudspeaker, a bending wave loudspeaker, a flat panel loudspeaker, a heil air motion transducer, a plasma arc speaker, and a digital loudspeaker.

FIG. **2** illustrates an architecture diagram of a haptic conversion system, according to one embodiment of the invention. In the illustrated embodiment, the haptic conversion system includes audio track module **210** and speaker **220**. Audio track module **210** is a module of an operating system for a device (such as a mobile device) configured to receive one or more pulse-code modulation ("PCM") audio buffers, and stream the one or more PCM audio buffers to speaker **220**, where each PCM audio buffer comprises one or more PCM audio data frames. In one embodiment, audio track module **210** is an Android AudioTrack module of an Android® operating system for a mobile device. Speaker **220** is a speaker configured to receive one or more PCM audio buffers and configured to output one or more audio effects. Speaker **220** can be, for example, a dynamic loudspeaker, an electrodynamic loudspeaker, a piezoelectric loudspeaker, a magnetostrictive loudspeaker, an electrostatic loudspeaker, a ribbon and planar magnetic loudspeaker, a bending wave loudspeaker, a flat panel loudspeaker, a heil air motion transducer, a plasma arc speaker, and a digital loudspeaker.

The haptic conversion system also includes a haptic conversion module **230**, according to the embodiment. In

certain embodiments, haptic conversion module **230** is identical to haptic conversion module **16** of FIG. **1**. In the illustrated embodiment, haptic conversion module **230** is comprised of two sub-modules: reverb module **231** and boombox module **232**. However, this is merely an example embodiment, and in alternate embodiments, haptic conversion module **230** can be comprised of any number of sub-modules, or haptic conversion module **230** can be a single module.

According to the embodiment, reverb module **231** is configured to intercept the one or more audio buffers that audio track module **210** streams to speaker **220**. Reverb module **231** is further configured to send each audio data frame of each audio buffer to boombox module **232**. Boombox module **232** is configured to analyze each audio data frame and calculate a maximum value for each audio data frame. The calculating of the maximum value for each audio data frame, performed by boombox module **232**, is further described in greater detail in relation to FIGS. **4**-**7**. Boombox module **232** is further configured to return the maximum value for each audio data frame to reverb module **231**.

The haptic conversion system also includes a haptic effect player module **240** and an actuator **250**. Haptic effect player module **240** is a module that is embedded within a device (such as a mobile device), and that is configured to play one or more haptic effects at an actuator by sending one or more haptic signals to the actuator. In one embodiment, haptic effect player module **240** is a TouchSense Player® module by Immersion Corporation. Actuator **250** is an actuator configured to receive one or more haptic signals, and configured to output one or more haptic effects. In certain embodiments, actuator **250** is an actuator configured to receive a single control parameter (such as a magnitude parameter), where the single control parameter is used to control a magnitude of a periodic effect when played through the actuator. Actuator **250** can be, for example, an electric motor, an electro-magnetic actuator, a voice coil, a shape memory alloy, an electro-active polymer, a solenoid, an ERM, or a LRA.

According to the embodiment, reverb module **231** is configured to use the maximum value of the audio data frame returned by boombox module **232** to create a haptic signal, where the haptic signal is a periodic effect, and where the maximum value defines an amplitude of the haptic signal. In certain embodiments, the haptic signal is a periodic effect at a resonant frequency of actuator **250**. Reverb module **231** is further configured to call an application program interface ("API") of haptic effect player module **240** and send haptic effect player module **240** the maximum value of the audio data frame as a parameter of the API. In certain embodiments, the API of haptic effect player module **240** is a "PlayPeriodicEffect" API of a TouchSense Player® module by Immersion Corporation. The API of haptic effect player module **240** sends the maximum value of the audio data frame to actuator **250**, where the actuator **250** is configured to play an appropriate periodic effect based on the maximum value of the audio data frame. According to the embodiment, the maximum value of the audio data frame serves as an amplitude parameter of actuator **250**, and the changing of the amplitude parameter of actuator **250** plays an appropriate periodic effect within actuator **250**. By playing a periodic effect, actuator **250** produces a haptic effect.

FIG. **3** illustrates a flow diagram of functionality performed by a haptic conversion system, according to one embodiment of the invention. In one embodiment, the functionality of FIG. **3**, as well as the functionality of FIG. **8**, is implemented by software stored in memory or other

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computer-readable or tangible media, and executed by a processor. In other embodiments, the functionality may be performed by hardware (e.g., through the use of an application specific integrated circuit ("ASIC"), a programmable gate array ("PGA"), a field programmable gate array ("FPGA"), etc.), or any combination of hardware and software. Furthermore, in alternate embodiments, the functionality may be performed by hardware using analog components.

According to the embodiment, the haptic conversion system includes an operating system **300**, a reverb module **301**, and a boombox module **302**. Operating system **300** is an operating system of a device (such as a mobile device). In the illustrated embodiment, operating system **300** is an Android® operating system for a mobile device. Reverb module **301** and boombox module **302** are sub-modules of a haptic conversion module (such as haptic conversion module **16** of FIG. **1**). In certain embodiments, reverb module **301** and boombox module **302** are identical to reverb module **231** and boombox module **232**, respectively, of FIG. **2**.

According to the embodiment, at **305**, an application configured to create an audio signal is created. The application is any application that can be executed within operating system **300**. In the illustrated embodiment, the application is an Android® application. The flow proceeds to **310**. At **310**, a "SoundPool" object is created by the application, where a SoundPool object is an instance of a SoundPool API (which is an Android® API), where a SoundPool object manages and plays audio resources for the application. The SoundPool object can include a collection of audio samples that can be loaded into a memory of a device from a resource stored within the device, or from a file stored within a file system of the device. The SoundPool object can decode the collection of audio samples into a raw 16-bit PCM mono or stereo buffer. The flow proceeds to **315**. At **315**, other audio objects are created by the application, where the other audio objects are instances of other audio APIs. The other audio objects can also decode audio samples into a 16-bit PCM audio buffer. The flow proceeds to **320**. At **320**, an AudioTrack object is created by either the SoundPool object or one of the other audio objects. An AudioTrack object is configured to receive one or more PCM audio buffers and stream the one or more PCM audio buffers.

The flow proceeds to **325**. At **325**, a reverb object is created. A reverb object is an instance of reverb module **301**, where the reverb object is configured to process one or more audio data frames of a PCM audio buffer sent by the AudioTrack object, as previously described in relation to FIG. **2**. The flow proceeds to **330**. At **330**, one or more settings of the reverb object are set. Example of reverb settings include: enable/disable haptic conversion, enable/disable haptic conversion for media, select a strength of haptic conversion from three selections (e.g., light, moderate, and strong), and select one or more applications (for example, from a list) for which haptic conversion is enabled. In certain embodiments, the above settings are stored in an extensible markup language ("XML") file. The above settings can be read from the XML file and stored within the reverb object, where the reverb object can be enabled for certain applications, and disabled for other applications. In certain embodiments, three values, identified as strength, density, and sharpness, are based on three factors: (1) strength setting (e.g., light, moderate, and strong), (2) haptic theme (that maps user interface events with haptic effects), and (3) actuator type. The strength, density, and sharpness values can be generated and stored within the reverb object.

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The flow proceeds to **335**. At **335**, a boombox object is created by the reverb object. A boombox object is an instance of boombox module **302**, where the boombox object is configured to receive an audio data frame from the reverb object, generate a maximum value of the audio data frame, and send the maximum value of the audio data frame to the reverb object, as previously described in relation to FIG. **2**. In certain embodiments, the strength and density values that are generated and stored within the reverb object can also be stored within the boombox object.

The flow proceeds to **340**. At **340**, the reverb object sends an audio data frame of a PCM audio buffer, that is received from an AudioTrack object, to the boombox object. The flow proceeds to **345**. At **345**, the boombox object samples data contained within the audio data frame. Such sampling is further described in greater detail in relation to FIGS. **4-7**. The flow proceeds to **350**. At **350**, the boombox object translates the data contained within the audio data frame into a single voltage value (i.e., a maximum value). Such translation is also further described in greater detail in relation to FIGS. **4-7**. The boombox object then returns the single voltage value to the reverb object. The flow proceeds to **355**. At **355**, the reverb object performs magnitude filtering on the single voltage value. Such magnitude filtering is also further described in greater detail in relation to FIGS. **4-7**. In certain embodiments, the sharpness value that is generated and stored within the reverb object is used to perform the magnitude filtering on the single voltage value. The flow proceeds to **360**. At **360**, the reverb object plays a periodic effect at an actuator using the single voltage value. By playing the periodic effect at the actuator, the reverb object causes the actuator to produce a haptic effect.

As previously described, a haptic conversion module (such as haptic conversion module **16** of FIG. **1**) processes an audio signal, contained within a PCM audio data buffer. As also previously described, the processing of the audio signal includes sampling each audio data frame of a PCM audio data buffer, calculating a maximum value for each audio data frame of a PCM audio data buffer, and magnitude filtering. Such processing of the audio signal is now described in greater detail.

According to certain embodiments, an envelope of the audio signal is first extracted. An envelope can be extracted using all frequencies of an original audio signal or a filtered version of the original audio signal. However, the envelope itself does not have the same frequency content as the original audio signal.

In one embodiment, an audio data frame is taken from the audio signal. As an example, an audio data frame may have a frame length of 1 ms. As another example, the audio data frame may have a frame length of 10 ms. A 1 ms audio data frame captures the envelope of frequencies above 500 Hz but lower frequencies are not captured, and "leak" through. A 10 ms frame captures the envelope of frequencies above 50 Hz, etc. In one embodiment, an absolute value of each sample in the frame is computed. In an alternate embodiment, a square of each sample in the frame is computed, rather than an absolute value. Such processing constitutes the sampling of an audio data frame performed by a haptic conversion module (such as haptic conversion module **16** of FIG. **1**).

A maximum value "V_1" of the absolute sample values (or the square sample values in an alternate embodiment) is computed. The maximum value, "V_1" can then be converted using a linear conversion function, as described below in relation to FIG. **4**.

FIG. 4 illustrates a linear conversion function 400 that is applied to control a range of an output value, according to one embodiment of the invention. According to the embodiment, linear conversion function 400 can be applied to control a range of the output value "V_1" to obtain a new value "V_2," as illustrated in FIG. 4. According to the illustrated embodiment, "x_0" can vary within a given range, such as [2 . . . 20]. "x_0" defines the minimum value "V_1" that will be converted into a new value "V_2". "y_{max}" can vary within a given range, such as example [60 . . . 255]. "y_{max}" defines the maximum converted value "V_2". If "V_1" is less or equal to "x_0", the output value "V_2" is equal to 0. If "V_1" is greater than "x_0", the output value "V_2" is obtained by multiplying "V_1" by the slope of the function. "V_2" is clamped and cannot be greater than "V_{max}". In an alternate embodiment, a more general mapping using (x_0, y_0) and (x_1, y_{max}) can also be used. Such processing constitutes the calculating of a maximum value of an audio data frame performed by a haptic conversion module (such as haptic conversion module 16 of FIG. 1).

Thus, according to the embodiment, an envelope of an audio signal is mapped to an amplitude of a haptic signal, where the amplitude of the haptic signal is filtered. In an alternate embodiment, the envelope of the audio signal can first be filtered, and then the filtered envelope of the audio signal can be mapped to an amplitude of a haptic signal.

Magnitude filtering, performed by a haptic conversion module (such as haptic conversion module 16 of FIG. 1), is now described in greater detail. A magnitude (or strength) "V_3" of a haptic effect is computed using the previous value "V_2." In certain embodiments, "V_3" can be mapped to a frequency. In other embodiments, "V_3" can be mapped to a set of frequency values. If "V_2" of iteration "i" is smaller than "V_2" of iteration "i–1", then the output "V_3" can be set to zero or some other small value, or else the output remains unchanged ("V_3"="V_2"). This specific technique can capture the peak values of the signal that represents a haptic event, and automatically associate to that haptic event an independent haptic effect. This technique can also be used to let an actuator settle down before the next haptic event is played, and thus, avoiding saturating a user with too much haptic information. In an alternate embodiment, smoother decay can be used, rather than a sharp drop to 0, when "V_2" of iteration "i" is smaller than "V_2" of iteration "i–1". A "sharpness" parameter, ranging from 0% to 100% can be used to define the amount of decay to be applied to "V_2": $V_3 = V_2 \times$ sharpness/m, where "m" is an integer divisor starting from 1 and increments as long as "V_2" of iteration "i" is smaller than "V_2" of iteration "i–1". According to the embodiment, "m" is reset back to 1 when "V_2" of iteration "i" is greater or equal to "V_2" of iteration "i–1", or in other words, when "V_3"="V_2". In certain embodiments, a sharpness value that is generated and stored within a reverb object is used as the sharpness parameter.

FIG. 5 illustrates an example computation 500 of a magnitude of a haptic effect that is created based on a digital audio signal, according to one embodiment of the invention. FIG. 5 illustrates an audio signal 510 sampled at 44100 Hz, a computed maximum value 520 for a 20 ms frame length, and pulses 530 obtained by magnitude filtering. According to the embodiment, pulses 530 capture an envelope of audio signal 510, and thus, pulses 530 can convey this information to a user through one or more haptic effects.

FIG. 6 illustrates an example calculation 600 of an envelope of a digital audio signal, according to one embodiment of the invention. FIG. 6 illustrates an audio signal 610, an envelope 620 obtained by low-pass filtering the absolute

value of audio signal 610, and an envelope value 630 computing the maximum of the absolute value over a certain frame, in this case of 20 ms.

Each frame of certain ms duration is processed in the frequency domain. Thus, in certain embodiments, a fast fourier transformation (FFT) of the frame can be used to extract the frequency content. In other embodiments, band-pass filters can be used to extract the frequency content.

In one embodiment, the frame information can be divided in bass or low frequency (for example, lower than 200 Hz), middle frequency (for example, between 240 Hz and 4000 Khz), and high frequency (for example, higher than 4400 KHz), where the middle frequency content and high frequency content is extracted using the content of the signal.

FIG. 7 illustrates an example calculation 700 of an envelope of a digital audio signal based on frequency content, according to one embodiment of the invention. According to the embodiment, a maximum value is obtained once an audio data frame is processed as previously described. In effect, three maximum values are obtained, one for low frequency bands, one for middle frequency bands, and one for high frequency bands. As illustrated in FIG. 7, graph 710 represents an unprocessed maximum value (based on the entire audio signal), graph 720 represents a maximum value that corresponds to a low frequency range of the audio signal, graph 730 represents a maximum value that corresponds to a medium frequency range of the audio signal, and graph 740 represents a maximum value that corresponds to a high frequency range of the audio signal.

According to the embodiment, when the signal starts to be processed, the first frame contains more middle frequency content (i.e., graph 730), given the maximum value obtained which is bigger than a frequency value in the low frequency band (i.e., graph 720) and high frequency band (i.e., graph 740).

According to the embodiment, a haptic effect can be played when the content frequency of the frame is different from the frequency content of the previous frame. As illustrated in FIG. 7, the haptic effect will be played at the locations signalized by arrows 701-707.

In alternate embodiments, variations of this technique can include: playing a pulse at every frequency change with magnitude as follows: maximum magnitude of the unprocessed frame; maximum magnitude corresponding to the frequency band; maximum magnitude allowed in Touch-Sense software only for the first frame.

In certain alternate embodiments, if the following frames have the same frequency content then: the magnitude of the unprocessed frame can be played; or the magnitude of the processed frame can be played; or a constant vibration, perhaps small, can be played as long as the frame has the same frequency content; or the magnitude can be varied based on power content in the frequency band.

In certain alternate embodiments, a different haptic effect can be played when a frame with a different frequency content is found.

Furthermore, human perception of sounds is not linear and depends on frequency of the sound. More particularly, humans are more sensitive to low frequencies than to high frequencies. Gender and age also affect the perception. Thus, in certain embodiments, there could be a compensation factor that boosts certain frequencies. The boosting factor can be based on human perception of sound or even preference of users where some frequency bands are enhanced manually. The software can enhance, in general, the high frequency content where it is known that users have a lower sensitivity to sound. This will allow the haptic effect for a

specific band to be of greater strength, and thus, enhancing the sound that, while perceived and noticed by a user's auditive system, might not have enough power.

In certain embodiments, a user of the haptic conversion system can customize the sound-to-haptic effect conversion algorithm. More specifically, the user can choose whether a digital audio signal is filtered using a low-pass filter, a high-pass filter, or a band-pass filter. Alternatively, or in addition to customizing a filter type, the user can specify filter parameters rather than choosing between pre-defined parameters. According to these embodiments, a haptic conversion system can display one or more user-defined parameters within a graphical user interface. The user can then either choose from one or more user-defined parameters, or specify one or more user-defined parameters, using the graphical user interface. For example, a user can choose a type of filter utilized in the sound-to-haptic effect conversion algorithm from among a low-pass filter, a band-pass filter, and a high-pass filter. As another example, the user can specify one or more cut-off frequencies, where instead of a value between 250 and 500 Hz, the user can specify any values. As yet another example, the user can specify a gain that is used in the sound-to-haptic effect conversion algorithm.

In certain embodiments, rather than utilizing system-defined filter parameters, the haptic conversion system can calculate filter parameters at runtime based on user-defined parameters. More specifically, a user can select a filter type. For example, a user can select a Butterworth design, a Bessel design, or a Chebyshev design, where for each design, a user can select a low-pass filter, a high-pass filter, a band-pass filter, or a band-stop filter. If a user selects a Chebyshev design, a user can also specify a ripple. A user can also specify a filter order, and a sample rate. A user can also specify one corner frequency if the user selected a low-pass filter or a high-pass filter, and two corner frequencies if the user selected a band-pass filter or a band-stop filter. A user can also select an optional additional zero value, and an optional lower limit of a magnitude scale. Furthermore, a user can also select whether the filter is designed by a bilinear transform method, or a matched z-transform method. The haptic conversion system can then calculate one or more filter parameters at runtime based on the parameters specified by the user.

FIG. 8 illustrates a flow diagram of the functionality of a haptic conversion module (such as haptic conversion module 16 of FIG. 1), according to one embodiment of the invention. At 810, a data frame of an audio signal is received. In certain embodiments, the audio signal is intercepted as the audio signal is streamed to a speaker. Also, in certain embodiments, the audio signal is a PCM audio buffer. The flow proceeds to 820.

At 820, a maximum value of the data frame is generated. In certain embodiments, the maximum value is generated by sampling the data frame to generate one or more sample values of the data frame, wherein the maximum value is a maximum value of the one or more sample values. In one embodiment, the one or more samples values are absolute values. In an alternate embodiment, the one or more sample values are square values. In certain embodiments, the maximum value is converted from an original maximum value using a linear conversion function. The flow proceeds to 830.

At 830, a haptic signal is generated based on the maximum value. In certain embodiments, the maximum value defines a magnitude of the haptic signal. Also in certain embodiments, the magnitude of the haptic signal is filtered.

Additionally, in certain embodiments where the magnitude of the haptic signal is filtered, a sharpness parameter is used to define an amount of decay to be applied to the magnitude of the haptic signal. The flow proceeds to 840.

At 840, the haptic signal is sent through an actuator to generate the one or more haptic effects. In certain embodiments, the haptic signal is a periodic effect. Also, in certain embodiments, the generating and the sending the haptic signal further includes passing the maximum value as a parameter to an application programming interface of a haptic effect player module.

Thus, according to an embodiment, a haptic conversion system intercepts audio data frames that are part of an audio signal, converts the audio data frames into a haptic signal where a maximum value of each audio data frame defines a magnitude of the haptic signal, and plays the converted haptic signal through an actuator to generate haptic effects. Based on the maximum value that defines the magnitude of the haptic signal, the strength of the haptic signal played through the actuator can be very strong, thus creating a richly defined haptic effect.

The features, structures, or characteristics of the invention described throughout this specification may be combined in any suitable manner in one or more embodiments. For example, the usage of "one embodiment," "some embodiments," "certain embodiment," "certain embodiments," or other similar language, throughout this specification refers to the fact that a particular feature, structure, or characteristic described in connection with the embodiment may be included in at least one embodiment of the present invention. Thus, appearances of the phrases "one embodiment," "some embodiments," "a certain embodiment," "certain embodiments," or other similar language, throughout this specification do not necessarily all refer to the same group of embodiments, and the described features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

One having ordinary skill in the art will readily understand that the invention as discussed above may be practiced with steps in a different order, and/or with elements in configurations which are different than those which are disclosed. Therefore, although the invention has been described based upon these preferred embodiments, it would be apparent to those of skill in the art that certain modifications, variations, and alternative constructions would be apparent, while remaining within the spirit and scope of the invention. In order to determine the metes and bounds of the invention, therefore, reference should be made to the appended claims.

We claim:

1. A non-transitory computer-readable medium having instructions stored thereon that, when executed by a processor, cause the processor to convert an audio signal into one or more haptic effects, the converting comprising:

receiving a plurality of data frames of the audio signal;

sampling each data frame to generate one or more sample values of each of the plurality of data frames;

determining a maximum value of each of the data frames based on the one or more sample values of each of the data frames;

generating a haptic signal based on the maximum value of each of the data frames;

filtering the magnitude of the haptic signal using a parameter to define an amount of decay of the haptic signal, and

sending the haptic signal to an actuator to generate the one or more haptic effects.

2. The non-transitory computer-readable medium of claim **1**, wherein the haptic signal comprises a periodic effect.

3. The non-transitory computer-readable medium of claim **1**, wherein the one or more sample values of the data frame are absolute values.

4. The non-transitory computer-readable medium of claim **1**, wherein the one or more sample values of the data frame are square values.

5. The non-transitory computer-readable medium of claim **1**, wherein the maximum value is converted from an original maximum value using a linear conversion function.

6. The non-transitory computer-readable medium of claim **1**, wherein a sharpness parameter is used to define a rate of decay to be applied to the magnitude of the haptic signal.

7. The non-transitory computer-readable medium of claim **1**, wherein the audio signal is a pulse-code modulation audio buffer.

8. The non-transitory computer-readable medium of claim **1**, wherein the generating and the sending the haptic signal further comprises passing the maximum value as a second parameter to an application programming interface of a haptic effect player module.

9. The non-transitory computer-readable medium of claim **1**, the converting further comprising extracting a frequency content from the data frame using a fast fourier transformation of the data frame.

10. The non-transitory computer-readable medium of claim **1**, the converting further comprising extracting a frequency content from the data frame using a band-pass filter.

11. The non-transitory computer-readable medium of claim **1**, the converting further comprising:

dividing the data frame into low frequency content, middle frequency content, and high frequency content; and

extracting the middle frequency content and high frequency content using content of the audio signal.

12. A computer-implemented method for converting an audio signal into one or more haptic effects, the computer-implemented method comprising:

receiving a plurality of data frames of the audio signal;

sampling each data frame to generate one or more sample values of each of the plurality of data frames;

determining a maximum value of each of the data frames based on the one or more sample values of each of the data frames;

generating a haptic signal based on the maximum value of each of the data frames;

filtering the magnitude of the haptic signal using a parameter to define an amount of decay of the haptic signal and

sending the haptic signal to an actuator to generate the one or more haptic effects.

13. The computer-implemented method of claim **12**, wherein the haptic signal comprises a periodic effect.

14. The computer-implemented method of claim **12**, wherein the one or more sample values of the data frame are absolute values.

15. The computer-implemented method of claim **12**, wherein the maximum value is converted from an original maximum value using a linear conversion function.

16. The computer-implemented method of claim **12**, the computer-implemented method further comprising extracting a frequency content from the data frame using a fast fourier transformation of the data frame.

17. The computer-implemented method of claim **12**, the computer-implemented method further comprising extracting a frequency content from the data frame using a band-pass filter.

18. The computer-implemented method of claim **12**, the computer-implemented method further comprising:

dividing the data frame into low frequency content, middle frequency content, and high frequency content; and

extracting the middle frequency content and high frequency content using content of the audio signal.

19. A haptic conversion system comprising:

a haptic conversion module, wherein the haptic conversion module comprises a first sub-module and a second sub-module; and

an actuator configured to generate one or more haptic effects;

wherein the first sub-module is configured to receive a plurality of data frames of an audio signal;

wherein the second sub-module is configured to sample each data frame to generate one or more sample values of each of the data frames;

wherein the second sub-module is further configured to determine a maximum value of each of the data frames based on the one or more sample values;

wherein the first sub-module is further configured to generate a haptic signal based on the maximum value of each of the data frames;

wherein the first sub-module is further configured to filter the magnitude of the haptic signal using a parameter to define an amount of decay of the haptic signal and

wherein the first sub-module is further configured to send the haptic signal to the actuator.

20. The haptic conversion system of claim **19**, wherein the haptic signal comprises a periodic effect.

21. The haptic conversion system of claim **19**, wherein the one or more sample values of the data frame are absolute values.

22. The haptic conversion system of claim **19**, wherein the second sub-module is further configured to convert the maximum value from an original maximum value using a linear conversion function.

23. The haptic conversion system of claim **19**, wherein the second sub-module is further configured to extract a frequency content from the data frame using a fast fourier transformation of the data frame.

24. The haptic conversion system of claim **19**, wherein the second sub-module is further configured to extract a frequency content from the data frame using a band-pass filter.

25. The haptic conversion system of claim **19**, wherein the second sub-module is further configured to:

divide the data frame into low frequency content, middle frequency content, and high frequency content; and

extract the middle frequency content and high frequency content using content of the audio signal.

26. A haptic conversion system comprising:

a haptic conversion module, and

an actuator configured to output one or more haptic effects;

wherein the haptic conversion module is configured to:

receive a plurality of data frames of an audio signal;

sample each data frame to generate one or more sample values of each of the plurality of data frames;

determine a maximum value of each of the data frames based on the one or more sample values of each of the data frames;

generate a haptic signal based on the maximum value of each of the data frames;

filter the magnitude of the haptic signal using a parameter to define an amount of decay of the haptic signal; and

send the haptic signal to the actuator.

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